



Muon Collider as a site filler for Fermilab

Diktys Stratakis

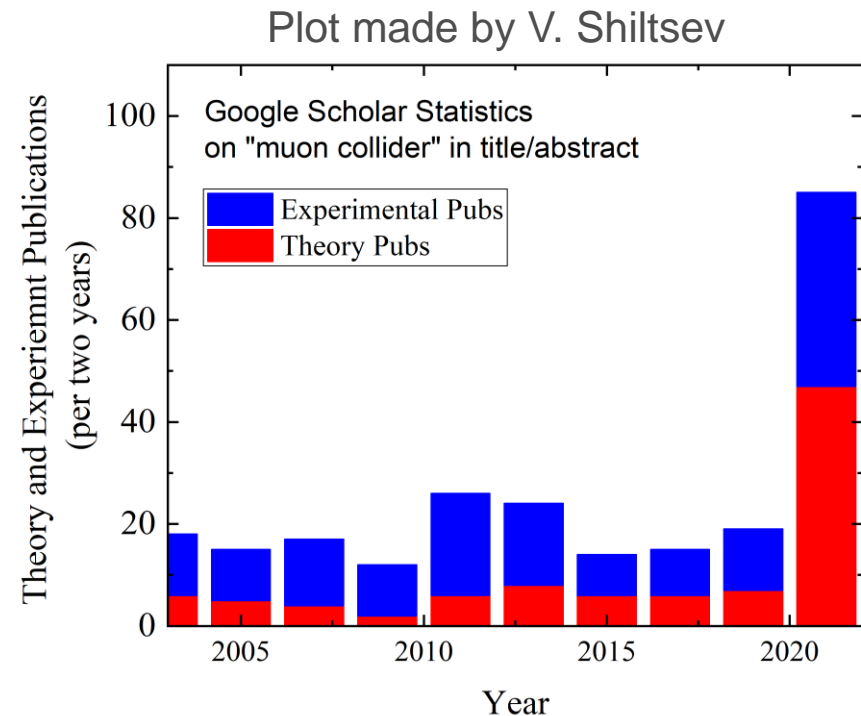
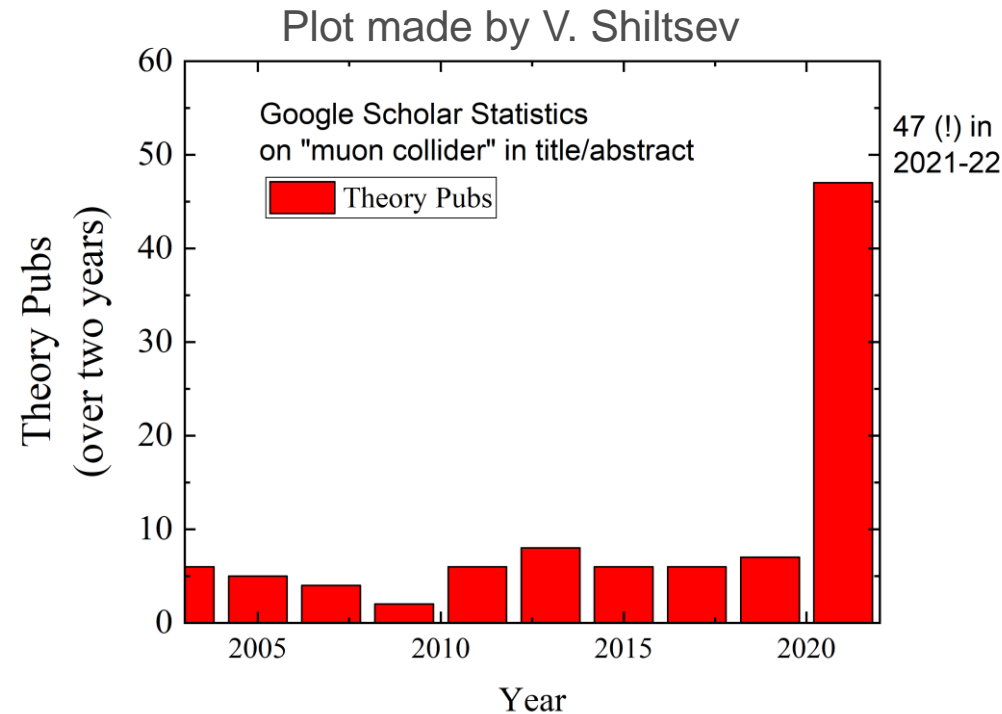
Snowmass Agora on Future Colliders: Muon Colliders

16 February 2022

Brief history

- Between 2011-2016 the Muon Accelerator Program (MAP) was formed to address key feasibility issues of a Muon Collider
 - Focused on a proton-driver based solution. Significant progress achieved
 - MAP was terminated in 2016 and most related work paused
- Since 2019, increasingly growing interest in muon colliders from the particle physics community, especially in Europe.
- In 2021, CERN Council has charged the EU Laboratory Directors Group to develop the Accelerator R&D Roadmap for the next decade:
 - Three community meetings organized with the goal to define the needed muon R&D with deliverables and demonstrators
 - **Strong participation from US scientists in these meetings – many of them served either as conveners or panel members**
- Muon Colliders are now part of the European Accel. R&D Roadmap

Muon Collider publication statistics



- Recently, there is a considerable increase in Muon Collider publications
- A clear indication of interest from the community

Preparation for Snowmass: Muon Collider Forum

- The Snowmass Energy, Theory and Accelerator Frontier Conveners have created a [Muon Collider Forum](#) to provide input to Snowmass on the muon collider based on the recent high-level of interest
- The intention of this informal organization is to not compete with other efforts but to have a US driven component.
- Muon Forum meets on a monthly basis and has invited several experts in the field to give presentations
- Two coordinators from each frontier



"Muon Forum": Discussion Forum on Muon Colliders

Forum Mailing List: **SNOWMASS-MUON-COLLIDER-FORUM@FNAL.GOV**

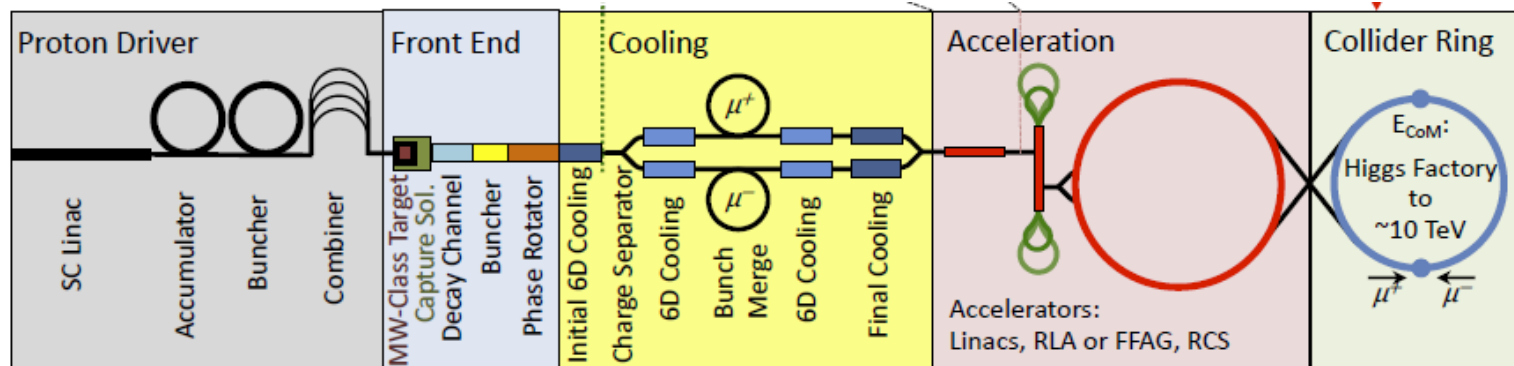
SLACK Channel: **#muon-collider-forum** under Snowmass Energy Frontier

Name	Institution	email	frontier
Derun Li	Lawrence Berkeley Lab	dli[at]lbl.gov	AF
Diktys Stratakis	Fermilab	diktys[at]fnal.gov	AF
Kevin Black	University of Wisconsin	kblack[at]hep.wisc.edu	EF
Sergo Jindariani	Fermilab	sergo[at]fnal.gov	EF
Fabio Maltoni	University of Bologna/CERN	maltoni.fabio[at]gmail.com	TF
Patrick Meade	Stony Brook University	patrick.r.meade[at]gmail.com	TF

Muon Collider Forum Outlook

- Build a strong collaboration between the particle physics and accelerator communities for Muon Collider (MC) research
- Make a strong physics case for a MC
- Organize dedicated workshops
 - Hosted an accelerator MC workshop recently (next slides)
- Write a joint MC Forum Report for Snowmass.
 - It will help to identify key areas where US can provide critical contributions to the global MC R&D efforts.
 - Present a "Fermilab Site-Filler" as one of options for hosting a MC in the future.
- The Report will also be useful for the Snowmass frontier summaries and possibly P5 deliberations.

Muon Collider components & parameters



μ -Collider Goals:
 126 GeV \Rightarrow
 $\sim 14,000$ Higgs/yr
 Multi-TeV \Rightarrow
 Lumi $> 10^{34} \text{cm}^{-2}\text{s}^{-1}$

Target parameters of IMCC (2022)

Tentative target parameters, scaled from MAP parameters

Parameter	Unit	3 TeV	10 TeV	14 TeV
L	$10^{34} \text{cm}^{-2}\text{s}^{-1}$	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14
$\langle B \rangle$	T	7	10.5	10.5
ϵ_L	MeV m	7.5	7.5	7.5
σ_E / E	%	0.1	0.1	0.1
σ_z	mm	5	1.5	1.07
β	mm	5	1.5	1.07
ϵ	μm	25	25	25
$\sigma_{x,y}$	μm	3.0	0.9	0.63

Snowmass process to give feedback on this

- MAP took a staged approach:
 - End-to-end design for a Neutrino Factory & a 125 GeV Higgs Factory.
 - Considered colliders at 1.5, 3 and 6 TeV
- Recent quotes from particle physicists:
 - “There are many things pointing to the 10 TeV energy scale as interesting”
 - “A Higgs factory isn’t *just* a low energy thing”

MC Forum: Accel. workshop on MC (Jan. 26, 2022)

- Define a path for US accelerator R&D contributions to the global effort
 - [Vladimir Shiltsev](#) – Synergies [\[Talk\]](#)
- Discuss potential US site fillers
 - [David Neuffer](#) (FNAL) – Fermilab site filler [\[Talk\]](#)
- Discuss synergies between US and IMCC:
 - Daniel Schulte – Synergies US – IMCC [\[Talk\]](#)
- Discuss technology status and R&D needs:
 - [Scott Berg](#) (BNL) – MC acceleration technology [\[Talk\]](#)
 - Christian Carli (CERN) – Neutrino flux mitigation [\[Talk\]](#)
 - [Tianhuan Luo](#) (LBNL) – RF technology [\[Talk\]](#)
 - [Nikolai Mokhov](#) (FNAL) – Neutrino flux mitigation [\[Talk\]](#)
 - Nadia Pastrone (INFN-Torino) – MDI [\[Talk\]](#)
 - [Katsuya Yonehara](#) (FNAL) – Targetry & Cooling [\[Talk\]](#)
 - [Alexander Zlobin](#) (FNAL) – Magnet technology [\[Talk\]](#)
- Discuss synergies with other accelerator efforts: Muon/Ion Collider [\[Talk\]](#)

[\[Details\]](#)

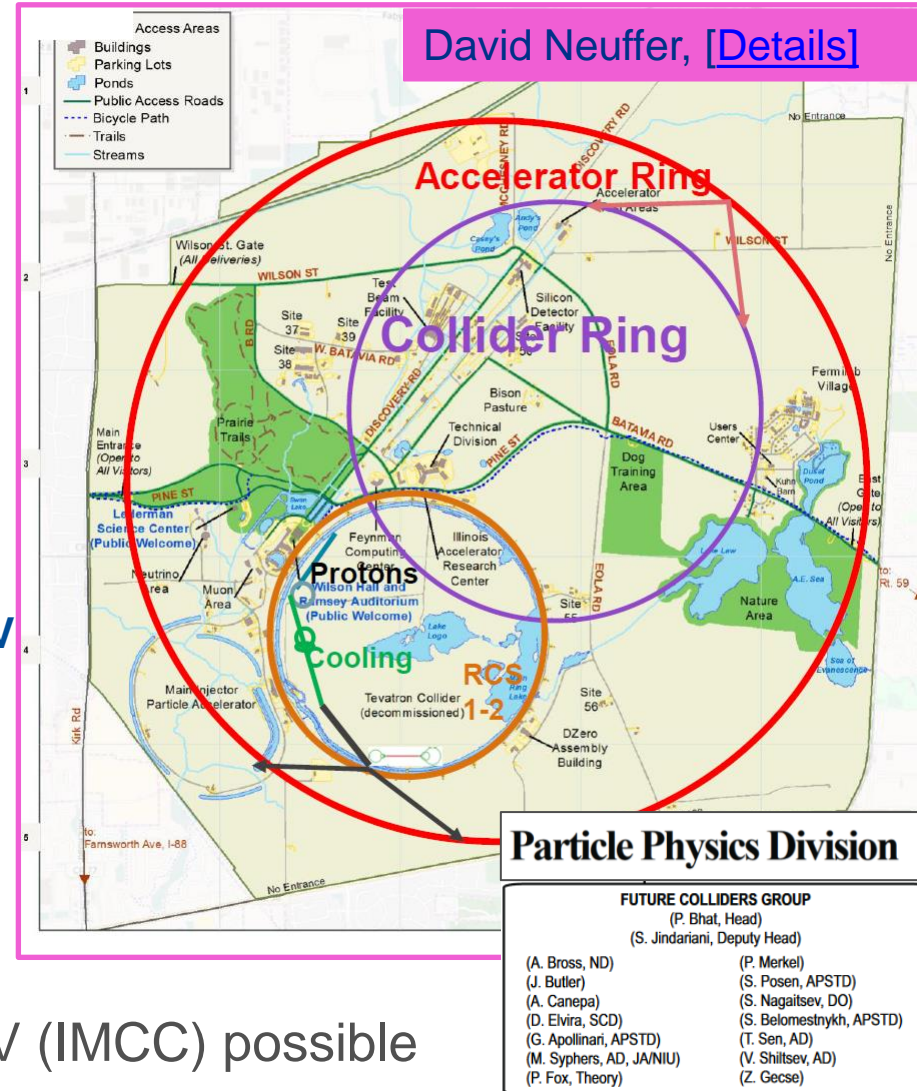
Workshop on Muon Driven Colliders

Jan 26, 2022, 10:00 AM → Jan 27, 2022, 1:00 PM US/Pacific

Zoom

A path for a Muon Collider at Fermilab

- A conceptual design is in place
- Proton source
 - PIP-II upgrade -> Target
- Ionization cooling channel
- Acceleration (3 stages)
 - Linac + Recirculating Linac → **65 GeV**
 - Rapid Cycling Synchrotrons #1, #2 → **1 TeV (Tevatron size)**
 - RCS #3 → **5 TeV (site filler)**
- 10 TeV collider
 - Collider radius: 1.65 km
- Staging @125 GeV (Higgs) or @ 3 TeV (IMCC) possible



Fermilab new formed *Future Colliders Group* is actively exploring filler option

Site filler: status, future R&D & synergies (1)

Needs & issues for FNAL site filler

- MW scale 8 GeV proton SRF linac

Proton Driver

- PIP-II will increase power to 1.2 MW
- **Synergy: With booster upgrades to > 2 MW**

Future possibilities

Target

- MAP considered 2-4 MW class. Materials: Liquid Mercury or Gallium jets. Carbon was also considered as a starter.

- Potential to “relax” power requirements with cooling improvements;
- **Synergy: With active FNAL target program.** Examples includes the 100 kW (Mu2e-II) and 1.2-2.4 MW LBNF program

Cooling

- Normal Cond. RF inside multi-Tesla field
- MAP considered SC solenoids @ 30 T
- MAP considered cooling to 25 μm (trans) but only 55 μm achieved
- MAP considered ~ km scale channels

- Showed 50 MV/m @ 3T; More tests needed
- NMR magnets @ 28 T; Record 32 T (NHMFL)
- Improve cooling designs: Consider integration of AI (Synergy: With FNAL AI group); Tremendous benefits with more cooling!

Site filler: status, future R&D & synergies (2)

Needs & issues for FNAL site filler

- RCS need dipoles that combine a SC 16 T DC field AND 500-1000 T/s ramp field with 4 T peak
- SC RF 1300 MHz at 50 MV/m
- Beam loading

Acceleration

- 8 T NbTi dipoles currently at LHC; 16 T considered for FCC-hh;
- Fermilab showed HTS ramp magnets at 290 T/s but with 0.6 T; More research is needed!
- 1300 MHz at 35 MV/m demonstrated for ILC
- **Synergy: US Magnet Development Program (MDP)**
- **Synergy: Test and simulation of beam loading with RF @ FAST (Fermilab)**

Future possibilities

Collider Ring

- Collider ring with arc 16 T dipoles with 15 cm bore
- Neutrino flux radiation
- Only lattices up to 6 TeV studied

- US-MDP 120 mm ID, 12-15 T dipole demonstrators with Nb₃Sn coils (3-4 years)
- Fermilab has x10 higher dose limits than Europe: Neutrino mitigation @ 100 m depth; Additional mitigation with more cooling.
- Detailed lattice designs for 10 TeV needed
- **Synergy: US MDP program**

A few comments for a Higgs factory

- Based on recent MC Forum meetings it appears that the particle physics community is interested for a Higgs factory
- Considerable overlap between the accelerator complex required for a 125 GeV Higgs Factory with that required for a multi-TeV machine
 - MAP studies suggest that proton driver, front end, initial cooling, and 6D cooling systems are can be shared with a multi-TeV collider
- The Higgs Factory configuration could be an ideal accelerator demonstration for subsequent higher energy stages.
- Non-overlapping systems and issues:
 - Final Cooling system; High-Energy Acceleration systems; Neutrino radiation mitigation techniques
 - Much simpler: More established acceleration methods; Collider ring has a circumference of 300 m.

A muon collider as a Higgs factory

[\[Details\]](#)

D. Neuffer, M. Palmer, Y. Alexahin (Fermilab) C. Ankenbrandt (MUONS, Inc., Batavia) J.P. Delahaye (SLAC)

Summary

- There has been a recent considerable growth of interest about MC from the particle physics community:
 - Significant growth of related publications
 - Significant growth of related workshops
 - Formation of the IMCC in progress
 - US Muon Forum actively participates in the process
- A recent survey on ongoing work and planned White Papers submissions show a continuing STRONG interest from the US side! [[Details](#)]
- We hope that Snowmass/ P5 would consider at some level the muon collider program in the US
 - Provide funding for R&D and collaboration with IMCC
 - Further develop the site-filler concept